J8.3 LIMB CORRECTION OF INDIVIDUAL INFRARED CHANNELS USED IN RGB COMPOSITE PRODUCTS

LIMB CORRECTION OF INDIVIDUAL INFRARED CHANNELS USED IN RGB COMPOSITE PRODUCTS

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1. INTRODUCTION

Current satellites monitor multiple spectral channels in visible and infrared wavelengths to gather useful information about the atmosphere and surface. Future satellites will further expand upon these capabilities by monitoring additional spectral channels. Due to the vast amount of imagery available, it is difficult to use the information from all of these channels operationally. Red-Green-Blue (RGB) products address this issue and aid the operational forecast community by combining information from several infrared channels into one composite image. RGB composites contain more qualitative information than single channel imagery alone and enhance the situational awareness of operational forecasters, allowing them to make decisions in a more efficient and timely manner. RGB composites are designed to address a specific forecast problem, such as airmass characteristics (Air Mass RGB) or airborne dust (Dust RGB). Since GOES-R will have the capability to produce high resolution RGB composites, proxy products are currently being derived from polar-orbiters in order to give operational forecasters experience interpreting RGBs prior to the launch of GOES-R in 2016.

Unfortunately, infrared imagery, particularly from polar-orbiters, is adversely affected by limb effects. The limb effect, or limb-cooling, occurs as the satellite scans from nadir to the limb, increasing the optical path length of the absorbing atmosphere. This leads to greater atmospheric absorption and anomalously lower measured brightness temperatures at large scan angles. For infrared channels most sensitive to water vapor and ozone, anomalous cooling of 5-10 K is often observed as the sensor scans from nadir to the limb (Fig. 1). As a result, RGB composites created from these channels can only be reliably interpreted close to nadir, reducing the coverage of an already temporally and spatially limited product. Additionally, limb effects make the comparison of similar RGB products from multiple satellite sensors difficult.

The Air Mass RGB is designed to aid forecasters in identifying important airmass characteristics, such as atmospheric water vapor and tropopause height. The Air Mass RGB depicts vertical water vapor difference in red, an estimate of tropopause height in green, and the 200-500 hPa layer water vapor in blue. The Dust RGB separates airborne dust from thin clouds, which often look similar in individual infrared bands. The Dust RGB indicates the optical thickness of clouds and aerosols in red, cloud particle phase in green, and the temperature of the surface in blue, which is retrieved from the 10.8 µm brightness temperature (T_B). Therefore, airborne dust is typically indicated in the Dust RGB as magenta, but

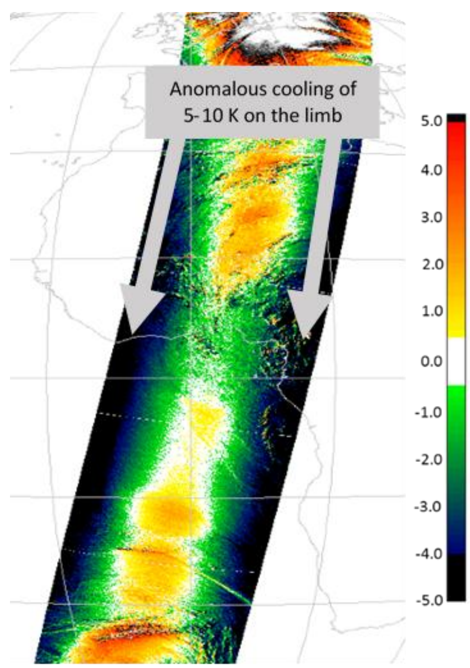

Fig. 1. 2014 Oct 29 0130 UTC Brightness Temperature Difference (BTD) between Aqua MODIS 6.7 µm and SEVIRI 6.3 µm. The Aqua MODIS 6.7 µm image has already been bias-corrected to account for channel differences between the Aqua MODIS 6.7 µm and the SEVIRI 6.3 µm channel.

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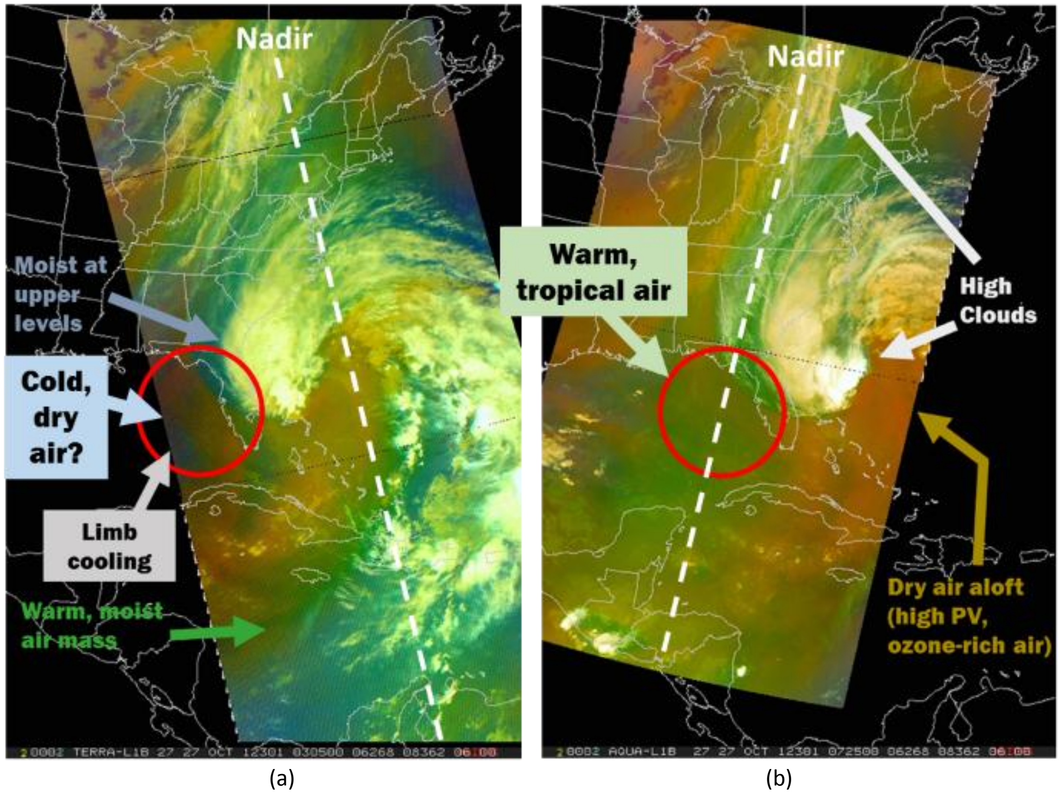


Fig. 2. 2012 October 27 (a) 0305 UTC Terra and (b) 0725 UTC Aqua uncorrected MODIS Air Mass RGB composites depicting a developing Hurricane Sandy.

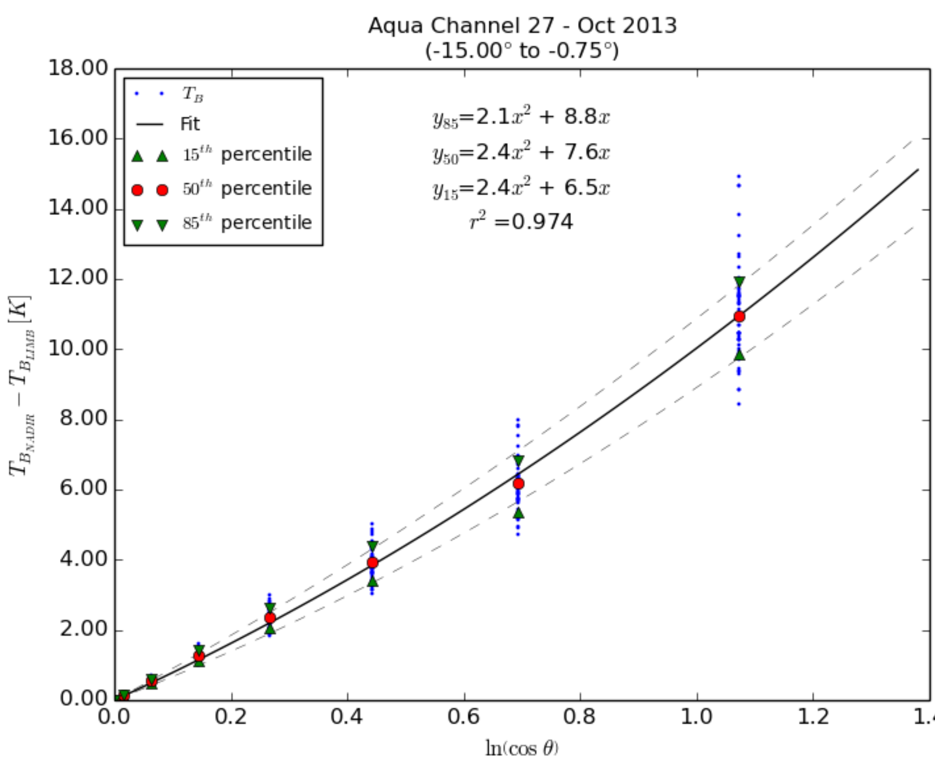


Fig. 3. Plot of the Aqua MODIS Channel 27 (6.7 µm) simulated brightness temperatures generated from 2013 October ECMWF profiles. The natural logarithm of the cosine of the satellite zenith angle (abscissa) is related to the T_B difference between nadir and the limb (ordinate) by a quadratic function.

can range from purple to pink depending on the height, due to a large red contribution. The RGB recipes were developed by the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT), and tables describing the Air Mass and Dust RGB recipes in detail can be found in Appendix A (Fig. 9 and 10). Additional information about RGBs can also be found online at http://weather.msfc.nasa.gov/sport/training/.

Figure 2 demonstrates the challenges of interpreting infrared imagery that has not been corrected for limb effects. The feature circled in red in Fig. 2a is located on the limb of the Terra MODIS (Moderate Resolution Imaging Spectroradiometer) Air Mass RGB. The airmass feature is characterized by little to no green contribution, indicating a low tropopause height, and a large contribution of red and blue, indicating very little moisture and cold surface temperatures. As such, this feature appears to be cold, dry air. However, the same feature, when observed at nadir in the Aqua MODIS Air Mass RGB (Fig. 2b), can correctly be identified as warm, tropical air. Clearly, limb-cooling prevents the confident interpretation of RGB features at large scan angles and may even lead forecasters to misinterpret certain features. Therefore, to fully exploit the advantages of RGB products, the individual infrared channels must be corrected for limb effects prior to creating the RGB composites.

Previous studies (e.g., Soden and Bretherton 1993, Moody et al. 1999, Wimmers and Moody 2001) have demonstrated a limb correction technique for water vapor channels from geostationary satellites using satellite pairs. However, this technique cannot be applied to polar-orbiting satellite channels, since polar-orbiting satellite pairs do not frequently occur. Therefore, this study develops a limb correction methodology that can be applied to polar-orbiting satellite infrared channels using varying limb correction coefficients.

2. DATA AND METHODOLOGY

A subset of European Center for Medium-Range Weather Forecasting (ECMWF) Re-analysis (ERA-Interim) cloud-free profiles of temperature, specific humidity, and ozone mixing ratio were used in this study. The profiles were globally distributed and ranged from March 2013 through February 2014 to account for a wide variety of atmospheric conditions. Simulated top-of-atmosphere T_B were calculated at varying satellite zenith angles (0 – 70 degrees) from the model profiles using the Joint Center for Satellite Data Assimilation (JCSDA) Community Radiative Transfer Model (CRTM; Han et al. 2006).

The change in simulated T_B from nadir to the limb and the natural logarithm of the cosine of the satellite zenith angle (θ) are related by a quadratic function of the form

$$y = C_2x^2 + C_1x \quad (1)$$

where the least-square fit parameters, C_1 and C_2, are defined as the limb correction coefficients, which are unique to each channel and vary latitudinally and seasonally (Fig. 3; Joyce et al. 2001). Using the limb correction coefficients statistically derived from CRTM simulated T_B, individual infrared channel imagery can be limb-corrected using the following equation:

$$T_{corr} = T_{raw} - C_1\ln(\cos\theta) - C_2\ln(\cos\theta)^2 \quad (2)$$

where T_{corr} is the limb-corrected T_B, T_{raw} is the uncorrected T_B, θ is the satellite zenith angle, and C_1 and C_2 are the limb correction coefficients. From this equation, it can be determined that, at θ=60°, an error of 1.0 in the calculation of C_1 and C_2 corresponds to an error of 0.7 K and 0.5 K, respectively, in T_B at the limb.

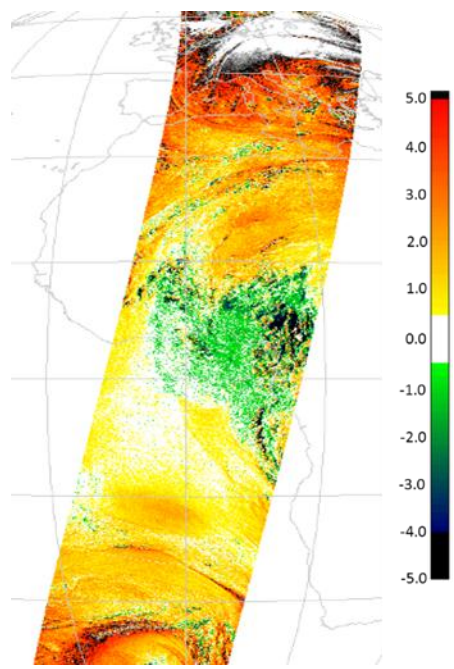
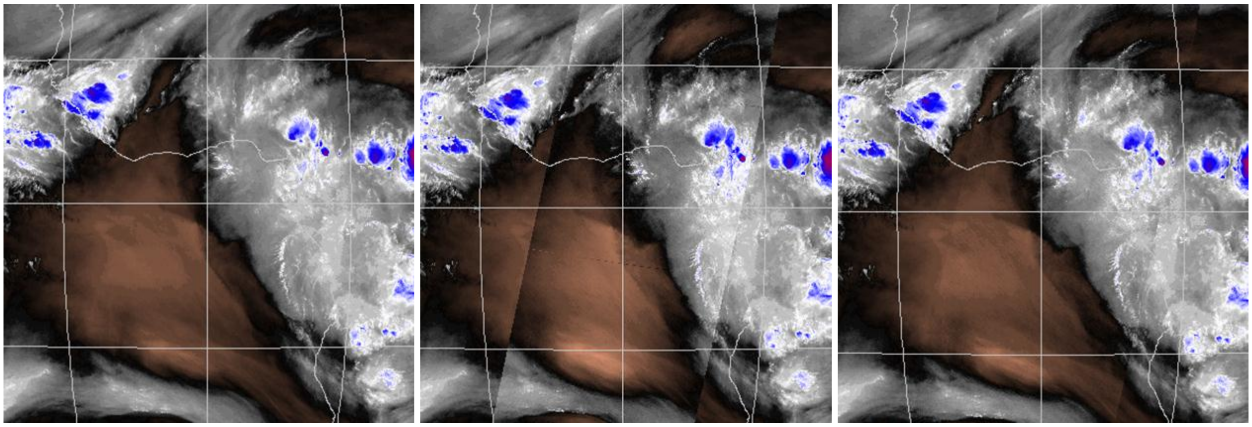
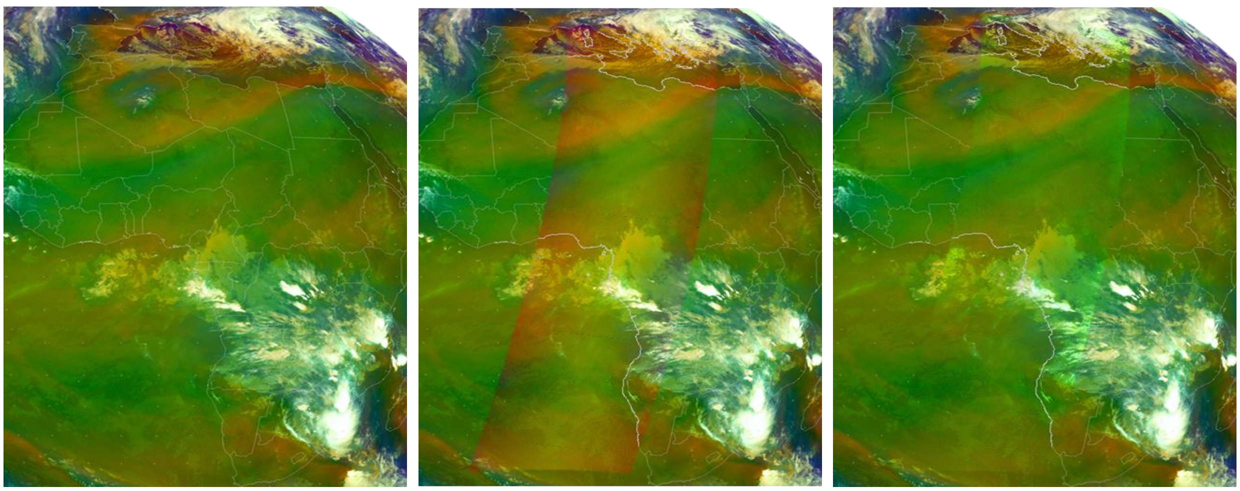


Fig. 4. 2014 Oct 29 0130 UTC BTD between Aqua MODIS 6.7 µm (limb-corrected) and SEVIRI 6.3 µm.



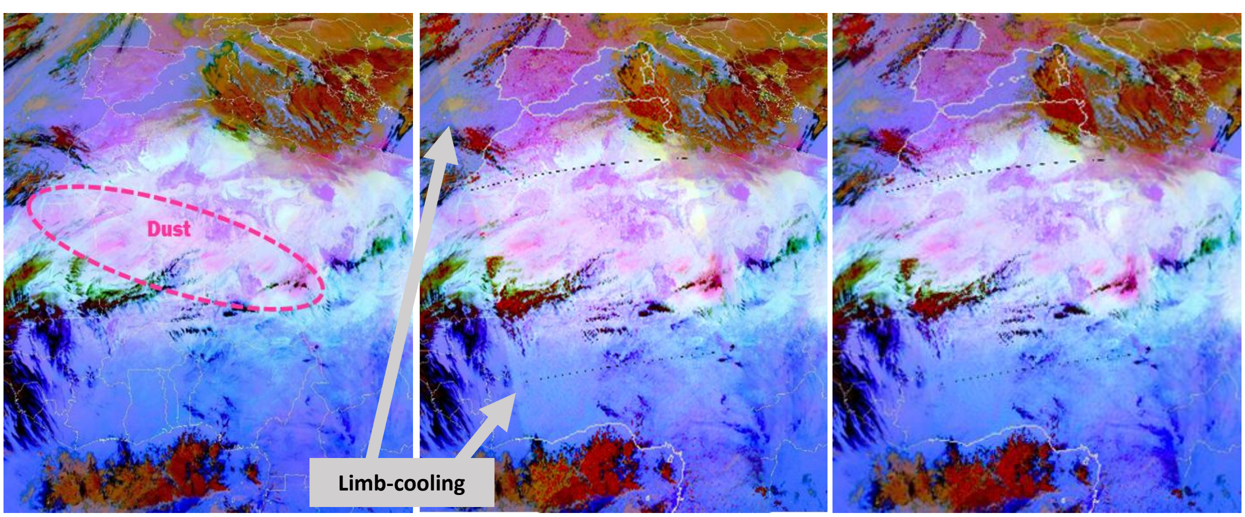
(a) (b) (c)

Fig. 5. 2014 October 29 0130 UTC (a) SEVIRI 6.3 µm, (b) uncorrected Aqua MODIS 6.7 µm merged with SEVIRI 6.3 µm, and (c) limb-corrected Aqua MODIS 6.7 µm merged with SEVIRI 6.3 µm water vapor imagery.



(a) (b) (c)

Fig. 6. 2014 December 29 (a) 0100 UTC SEVIRI Air Mass RGB (b) 0045 UTC uncorrected Aqua MODIS merged with 0100 UTC SEVIRI Air Mass RGB and (c) 0045 UTC limb-corrected Aqua MODIS merged with 0100 UTC SEVIRI Air Mass RGB.



(a) (b) (c)

Fig. 7. 2014 December 31 (a) 1300 UTC SEVIRI Dust RGB, (b) 1310 UTC uncorrected Aqua MODIS Dust RGB merged with 1300 UTC SEVIRI Dust RGB, and (c) 1310 UTC limb-corrected Aqua MODIS Dust RGB merged with 1300 UTC SEVIRI Dust RGB.

The case examples in Section 3 were created in the Man computer Interactive Data Access System (McIDAS) using Aqua MODIS calibrated radiances 5-min L1B swath 1km data retrieved from the Land Atmosphere Near real-time Capability for EOS (LANCE) data archive and Meteosat-10 SEVIRI full disk L1.5 image data obtained from EUMETSAT via NOAA's Satellite and Information Service (NESDIS) Satellite Applications and Research (STAR).

3. RESULTS AND DISCUSSION

Applying the limb correction methodology described in Section 2 to the uncorrected Aqua MODIS Channel 27 (6.7 µm) swath from Fig. 1 results in the limb-corrected Aqua MODIS Channel 27 swath in Fig. 4. A significant improvement in Aqua MODIS swath is observed, where the anomalous cooling from nadir to the limb shown in Fig. 1 is largely removed, and a less than 1 K difference between the SEVIRI and Aqua MODIS water vapor channels is achieved at the limb. Near the poles, the Aqua MODIS T_B are significantly warmer (3-5 K) than the SEVIRI T_B. However, this is evidence of limb-cooling in SEVIRI imagery, which increases from the equator poleward, rather than an error in the limb correction.

In addition to looking at the brightness temperature difference (BTD) between the Aqua MODIS and SEVIRI imagery, the individual channel imagery further illustrates the significant improvement resulting from the limb correction. Using the same Aqua MODIS swath from Fig. 1 and Fig. 4, Fig. 5 compares the uncorrected and limb-corrected Aqua MODIS water vapor imagery to the corresponding SEVIRI water vapor imagery. In the uncorrected Aqua imagery, the transition between the Aqua swath and the underlying SEVIRI imagery is clearly visible due to significant limb-cooling. However, after the limb correction is applied, the limb-corrected Aqua imagery completely blends into the underlying SEVIRI water vapor imagery. Although not shown, similar results are also observed in other infrared channels, including ozone and window channels. In some cases, the limb correction overcorrects for the limb effects, resulting in the MODIS imagery being 1-2 K warmer than SEVIRI at the limb.

Limb-corrected RGB composites are created by combining the appropriate limb-corrected infrared channels. A comparison of the uncorrected and limb-corrected Aqua MODIS Air Mass RGB to the corresponding SEVIRI Air Mass RGB is shown in Fig. 6. The uncorrected Aqua MODIS Air Mass RGB shows significant limb-cooling, indicated by very little green contribution near the swath edges. The limb-corrected Aqua MODIS Air Mass RGB demonstrates a significant improvement over the uncorrected Aqua MODIS Air Mass RGB and captures the correct RGB coloring shown in the SEVIRI Air Mass RGB. A slight over-correction of the ozone channel, as discussed previously, creates the bright green highlight along the edges of the limb-corrected Aqua MODIS swath. A similar example using the Dust RGB product is shown in Fig. 7. Since the channels used in the Dust product are less sensitive to water vapor, the limb effect is not as pronounced, but is still noticeable along the edges of the uncorrected Aqua MODIS swath. However, after the limb correction is applied, the limb-cooling is removed and the Aqua MODIS Dust RGB smoothly transitions into the SEVIRI Dust RGB.

Figure 8 compares the limb-corrected Terra and Aqua MODIS Air Mass RGBs from Fig. 2 to emphasize the improved interpretation of limb-corrected RGB composites. The feature located at the limb and circled in red in the limb-corrected Terra MODIS Air Mass RGB (Fig. 8a), which was incorrectly identified as cold, dry air in the uncorrected imagery (Fig. 2a), can now be correctly interpreted as warm, tropical air in the limb-corrected imagery. Additionally, the limb correction allows for the easy comparison between both the Terra and Aqua MODIS Air Mass RGB, enabling the RGBs from both sensors to be used jointly for analysis, improving the temporal resolution of the Air Mass RGB imagery.

4. SUMMARY AND CONCLUSIONS

This study demonstrates that limb-cooling can be removed from infrared imagery using latitudinally and seasonally dependent limb correction coefficients, which account for an increasing optical path length as scan angle increases. Furthermore, limb-corrected RGB composites provide multiple advantages over uncorrected RGB composites, including increased confidence in the interpretation of RGB features, improved situation awareness for operational forecasters, seamless transition between overlaid RGB composites, easy comparison of RGB products from different sensors, and the availability of high quality proxy products for the GOES-R era, as demonstrated by the case examples presented in Section 3. This limb correction methodology can also be applied to additional infrared channels used to create other RGB products, including those created from other satellite sensors, such as Suomi NPP Visible Infrared Imaging Radiometer Suite (VIIRS).

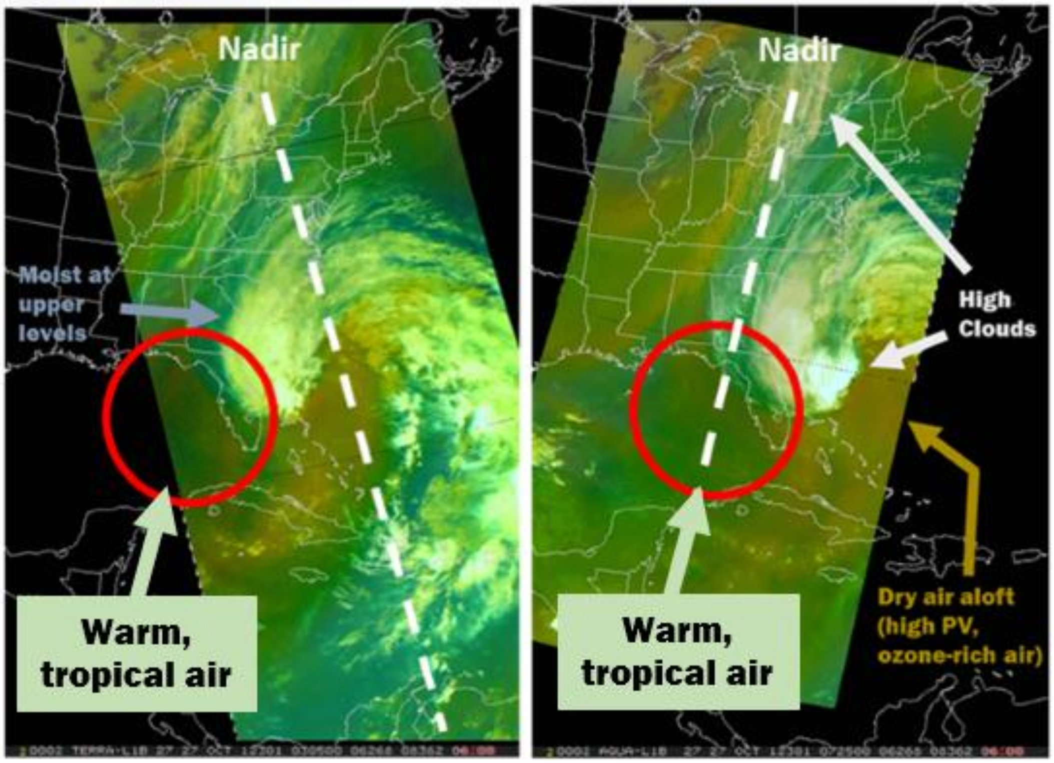


Fig. 8. 2012 October 27 (a) 0305 UTC Terra and (b) 0725 UTC Aqua MODIS limb-corrected Air Mass RGB composites depicting a developing Hurricane Sandy.

APPENDIX A

Color	Band / Band Diff.	Physically Relates to….	Little contribution to composite indicates…..	Large contribution to composite indicates …..
Red	6.7 – 7.3	Vertical water vapor difference	Moist conditions high levels	Dry conditions at high levels
Green	9.7- 10.8	Estimate of tropopause height based on ozone. Polar (tropical) air has higher (lower) ozone concentrations	Tropopause height is low. Typically indicates a polar air mass, where 9.7 has very cold brightness temperature compared to 10.7	Tropopause height is high. Likely a tropical air mass where the two channels will have similar brightness temperature values
Blue	6.7	Water Vapor in layer from ~200 – 500 mb	Dry at upper levels Warm brightness temperatures have little blue	Moist at upper levels Cold brightness temperatures result in lots of blue

Fig. 9. EUMETSAT Air Mass RGB recipe. Table retrieved from the NASA SPoRT Air Mass RGB quick guide (http://weather.msfc.nasa.gov/sport/training/rgb_airmass/RGB%20Air%20Mass%20Reference%20Guide.pdf).

Color	Band / Band Diff.	Physically Relates to….	Little contribution to composite indicates…..	Large contribution to composite indicates …..
Red	12.0 – 10.8	Optical thickness	Thin clouds. Difference is negative. Less of the 12um channel passes through the clouds (colder brightness temperature) than the 10.8um channel	Thick clouds or dust. Difference is positive. More of the 12um channel passes through the clouds (Warmer brightness temperature) than the 10.8um channel
Green	10.8 – 8.7	Particle phase (ice vs water) or composition	Ice particles or particles of similar characteristics have small difference	High clouds over desert regions – emission from surface overwhelms the relationship
Blue	10.8	Temperature of surface	Cold surface	Warm surface

Fig. 10. EUMETSAT Dust RGB recipe. Table retrieved from the NASA SPoRT Dust RGB quick guide (http://weather.msfc.nasa.gov/sport/training/rgb_dust/RGB%20Dust%20Reference%20Guide.pdf).

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